Performance of a 10 Gbps FSO System Implementing Novel Beam Tracking and a Dynamic Buffering Modem

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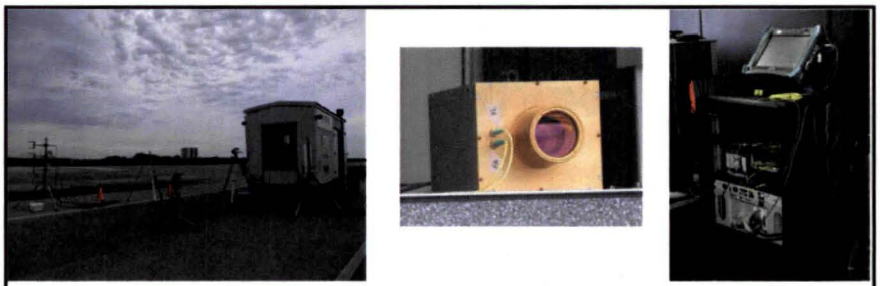
ABSTRACT

A 10 Gbps FSO system implements beam tracking, a high dynamic range optical receiver, and a dynamic buffering packet modem. Performance was characterized at the 4.5 km Shuttle Landing Facility at Kennedy Space Center Florida.

1. INTRODUCTION

Free space optical (FSO) links operating close to the ground experience beam wander and large optical power fades due to atmospheric turbulence. Common techniques to mitigate atmospheric effects include adaptive optics, expanded beams, and spatial diversity. A 10 Gbps FSO system has been integrated that minimizes SWaP and cost by using a high dynamic range buffering modem[1] and a compact 4 cm mono-static telescope that provides auto-acquisition and beam tracking with no external gimbal or beacon[2]. The system was characterized at the KSC-ISTEF 1 km laser test range (Dec 2011) and the KSC-SLF 4.5 km runway (Jan 2012). The purpose of this testing was to characterize range, packet loss performance, and develop system path loss and fade probability density function models over a range of atmospheric turbulence levels. UCF instrumented the propagation path with scintillometers recording turbulence strength, Cn^2, and inner scale, l_o, at the height of the beam. A weather station positioned nearby the scintillometer receivers recorded solar flux, the three-dimensional wind vector profile, relative humidity, air temperature, and ground temperature data. Section 2 provides the atmospheric path model. Section 3 provides the test results, extended range performance predictions, and conclusions.



(a) (b) (c)

Figure 1: (a) Setup at Shuttle Landing Facility, (b) Space Photonics tracking terminal, (c) Harris modem and test equipment.

2. ATMOSHPERIC PATH MODEL

A path model was fit to the test data to support parametric performance predictions[3]. Power in the bucket (PIB) is the average power that enters the receiver aperture. If P_{Tx} represents the laser power at the exit aperture of the transmitter, the average PIB at the receiver is

$$\langle \mathrm{PIB} \rangle = P_{Tx} \cdot \frac{D_{Rx}^2}{8W^2} \cdot \tau_{atm} \cdot \tau_{opt} \cdot \mathrm{SR}_{RP}; \quad D_{Rx} \le 2\sqrt{2}W \tag{1}$$

where D_{RX} is the receive aperture diameter, W is the free-space Gaussian beam radius of the laser beam in the receiver plane, τ_{atm} is the atmospheric transmission loss, τ_{opt} is the receiver transmission loss, and SR_{RP} is the strehl ratio in the receiver plane. The average power in the fiber (PIF) was calculated using the expression

$$\langle \mathrm{PIF} \rangle = \langle \mathrm{PIB} \rangle \cdot \tau_{\mathrm{fiber}} \cdot \mathrm{SR}_{\mathrm{DP}} \cdot \left(\frac{4}{\beta^2} \right) \qquad (2)$$

where τ_{fiber} represents internal losses in the telescope between the input fiber and the optical detector, $\mathrm{SR}_{\mathrm{DP}}$ is the strehl ratio in the detector plane, and $4/\beta^2$ represents the efficiency factor for the spot-size mismatch between the beam size at the entrance to the fiber and the fiber core size.

3. PERFORMANCE RESULTS

A path loss model was generated from the data collected at 1 km, 2 km, and 4.5 km for various turbulence levels. At fade margins above 25 dB a high dynamic range optical receiver alone was sufficient to keep packet loss low with data throughputs of 9.28 Gbps. At 4.5 km and $Cn^2 \sim$ 3E-13 (fade margin < 10 dB), the dynamic buffering modem reduced the packet loss from > 35% to less than 4%, though the data throughput was reduced to 0.52 Gbps to support the buffering required. Residual packet loss during buffering operation results from the optical channel not having perfect reciprocity and timing improvements needed in the prototype modem FPGA. Reciprocity data collected during the KSC-ISTEF 1 km test showed greater than 90% PIF correlation for optical power sampled at 5 kSps.

To predict the range of this system for commercial near the ground links we assume a transmit power of +15 dBm (31.6 mW) and a path height of 20 m. Vertical profile measurements of Cn^2 below 1 km show a mid-day altitude-dependent $h^{-4/3}$ behavior, where h denotes altitude[4]. The single pass path loss (telescopes already acquired) PIF model shows a maximum horizontal path range greater than 10 km using the 4 cm telescope, and a maximum horizontal path range > 18 km using a 10 cm version of the telescope. The range limiters in the system are currently the double pass path loss during acquisition and the 60 dB transmit/receive optical isolation for the mono-static lens configuration. Methods are being investigated to remove these limitations and are expected to extend the range while preserving the SWaP benefits of this system approach.

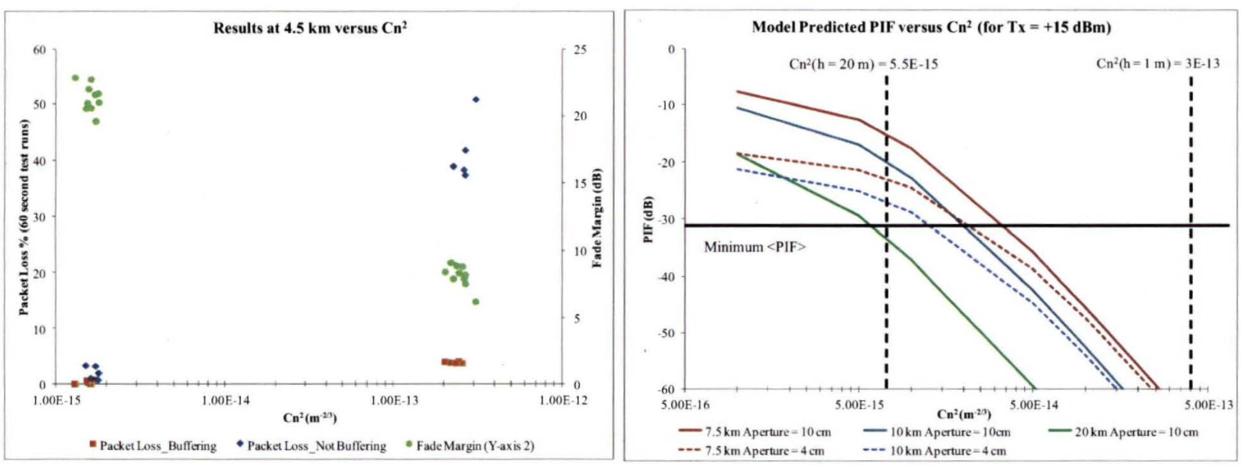


Figure 2: (a) Packet loss and fade margin (4.5 km test run), (b) Path loss models for 4 cm and 10 cm apertures.

4. REFERENCES

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